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(71) Applicant: **NOKIA TECHNOLOGIES OY** [FI/FI];
Karakaari 7, 02610 Espoo (FI).

(72) Inventors: **JEFFERS, Nicholas**; Shelma, Woodstock Rd,
Newtown Mount Kennedy, Wicklow, A63YH63 (IE).
O'CONNELL, Diarmuid; 2 Chanterlands, Athy Co. Kil-
dare, R14Y963 (IE).

(74) Agent: **NOKIA EPO REPRESENTATIVES**; Nokia
Technologies Oy, Karakaari 7, 02610 Espoo (FI).

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(54) Title: ELECTROMECHANICAL SENSORS

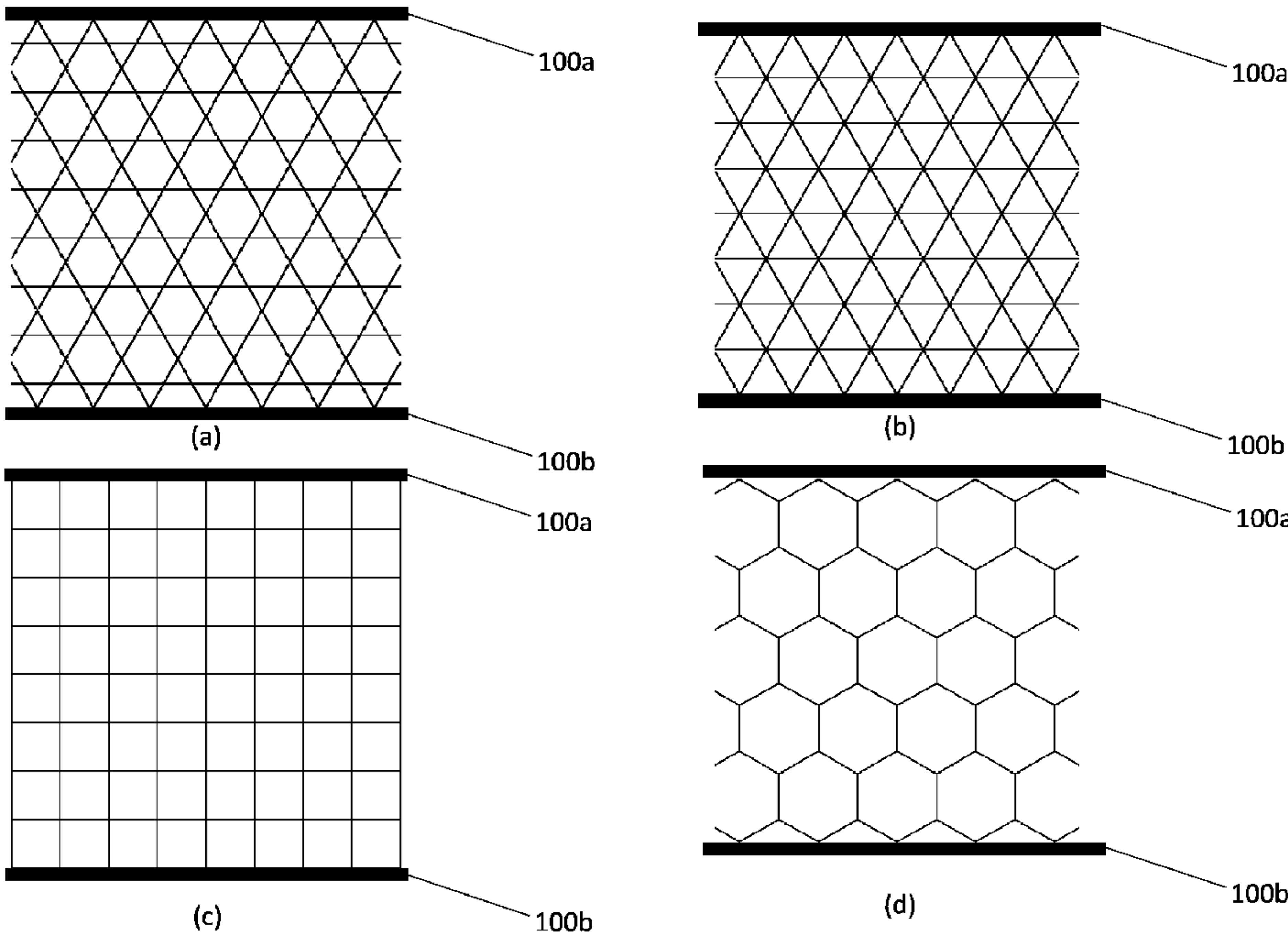


Figure 1

(57) Abstract: In some example, an electromechanical sensor, comprises a flexible matrix, and a strain sensing composite material supported within the flexible matrix.

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ELECTROMECHANICAL SENSORS

TECHNICAL FIELD

5 Aspects relate, in general, to electromechanical sensors, such as strain sensors.

BACKGROUND

Strain sensors can use electrical conductance or electrical resistance as a sensed property. That is, under strain, the geometry of a conductor comprised in such a sensor deforms, changing the
10 end-to-end resistance of the conductor, thereby enabling a measure of the strain applied to be determined.

SUMMARY

According to an example, there is provided an electromechanical sensor, comprising a flexible
15 matrix, and a strain sensing composite material supported within the flexible matrix. The strain sensing composite material can comprise graphene dispersed within a viscoelastic polymer. The flexible matrix can comprise one of: elastomeric polyurethane (EPU), acrylonitrile butadiene styrene (ABS), polycarbonate (PC) and polyetherimide (PEI). The flexible matrix can comprise a three-dimensional lattice structure defining a network of nodes, beams and cells. The strain
20 sensing composite material can be supported within cells of the lattice structure. The strain sensing composite material can be supported within beams and/or nodes of the lattice structure. An outer surface of the lattice structure can be so profiled as to increase surface area thereof, whereby to amplify support for the strain sensing material within the flexible matrix. An inner surface of a node and/or beam of the lattice structure can be so profiled as to increase surface
25 area thereof, whereby to amplify support for the strain sensing material within the said node and/or beam. The electromechanical sensor can further comprise a pair of conductive electrodes so positioned on opposing sides of the flexible matrix as to detect a change in resistance of the strain sensing composite material.

30 According to an example, there is provided a method for fabricating an electromechanical sensor, the method comprising additively manufacturing a flexible matrix, and depositing a strain sensing composite material within the flexible matrix. The strain sensing material can be additively deposited within the flexible matrix as the flexible matrix is manufactured. The method can further comprise depositing a pair of conductive electrodes on opposing sides of the flexible
35 matrix. The method can further comprise profiling an inner and/or outer surface of the flexible matrix. The flexible matrix can comprise a three-dimensional lattice structure defining a network of nodes, beams and cells, and wherein depositing the strain sensing composite material

comprises depositing the strain sensing composite material within cells of the lattice structure. The flexible matrix can comprise a three-dimensional lattice structure defining a network of nodes, beams and cells, and wherein depositing the strain sensing composite material comprises depositing the strain sensing composite material within beams and/or nodes of the lattice structure.

According to an example, there is provided user equipment, comprising a processor, and an electromechanical sensor as provided herein, wherein the processor can be configured to receive an input signal from the electromechanical sensor, and generate a measure representing an orientation and/or movement of the user equipment. The processor can derive a measure of resistance from the electromechanical sensor, and map the derived measure of resistance to a predetermined orientation and/or movement profile.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figures 1a-d are schematic representations of lattice structures for a flexible matrix according to an example;

Figure 2 is a schematic representation of the lattice structure of figure 1c according to an example;

Figure 3 is a schematic representation of the lattice structure of figures 1c and 2 according to an example;

Figure 4 is a schematic representation of user equipment according to an example;

Figure 5 is a schematic representation of user equipment according to an example; and

Figure 6 is a schematic representation of a wearable device according to an example.

DESCRIPTION

Example embodiments are described below in sufficient detail to enable those of ordinary skill in the art to embody and implement the systems and processes herein described. It is important to understand that embodiments can be provided in many alternate forms and should not be construed as limited to the examples set forth herein.

Accordingly, while embodiments can be modified in various ways and take on various alternative forms, specific embodiments thereof are shown in the drawings and described in detail below as examples. There is no intent to limit to the particular forms disclosed. On the contrary, all
 5 modifications, equivalents, and alternatives falling within the scope of the appended claims should be included. Elements of the example embodiments are consistently denoted by the same reference numerals throughout the drawings and detailed description where appropriate.

The terminology used herein to describe embodiments is not intended to limit the scope. The
 10 articles “a,” “an,” and “the” are singular in that they have a single referent, however the use of the singular form in the present document should not preclude the presence of more than one referent. In other words, elements referred to in the singular can number one or more, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises,”
 15 “comprising,” “includes,” and/or “including,” when used herein, specify the presence of stated features, items, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, items, steps, operations, elements, components, and/or groups thereof.

Unless otherwise defined, all terms (including technical and scientific terms) used herein are to be
 20 interpreted as is customary in the art. It will be further understood that terms in common usage should also be interpreted as is customary in the relevant art and not in an idealized or overly formal sense unless expressly so defined herein.

A strain gauge can be provided in the form of an electromechanical sensor that measures strain
 25 on an object. It changes its resistance according to the applied mechanical strain. This relationship is expressed using the gauge factor (GF). The GF of material is used to characterize a material's strain sensitivity and is defined by:

$$GF = \Delta R/R \cdot L/\Delta L = \Delta R/R \cdot l/\epsilon$$

30 or

$$\Delta R/R = GF \cdot \epsilon$$

where ΔR is the change in resistance, R is the initial resistance, ΔL is the change in length, and L is
 35 the initial length. That is, GF (or strain factor) is the ratio of relative change in electrical resistance R , to the mechanical strain ϵ .

A piezoresistive material is a type of material that changes its electrical resistivity as a result of mechanical stress. Semiconductors usually show piezoresistivity that can be used for a strain gauge. When a stress is applied to their crystal structure, the mobility of charge carriers changes, resulting in a measurable resistance change. In particular for example, doped silicon is a piezoresistive material and is widely utilized in integrated force/pressure sensors.

In certain applications, such as in medical applications for example, detectors with high sensitivity are desirable. For example, detection of the pulse of a patient may be carried out using table-top medical equipment based on optical detection of pulse waveforms at the patient's radial artery picked up by a cuff worn on the patient's index finger. However, this type of equipment is bulky, expensive and suited only to patient monitoring in a hospital or laboratory environment. This means that patient monitoring can only normally take place over short time periods. Also, detection or monitoring which is carried out in a hospital or laboratory environment can lead to spurious results caused by so-called "white coat syndrome", whereby measurements are influenced or corrupted by stress caused to a patient in such environments.

Other existing sensors suitable for medical use are wrist-worn sensors which employ optical technology embedded into a strap of a sensor for measuring blood oxygen levels as well as pulse rate, however such devices do not allow hi-fidelity pulse waveforms to be recorded and in addition such devices suffer from inaccuracy due to light contamination. An ECG electrode may be used to measure the electrical stimulus which stimulates the heart-pumping mechanism of a patient using electrical impedance measurements, however such measurements record the electrical stimulus to the heart rather than pulse waveforms at the patient's radial artery, from which additional useful medical information regarding patient health may be derived. Other sensors allow electrical impedance measurements to be obtained by incorporating electrodes onto a mobile device which can provide the equivalent of a single ECG measurement at the fingertip of a patient. In addition to medical applications, detectors with high sensitivity are desirable for use in other situations where it can be useful to determine the strain applied to an item or use strain information to determine other device metrics.

However, typically, sensors (such as mechanical sensors) have limited gauge factors of around two due to material and geometrical limitations. Other sensors, such as those described above based on piezoresistive materials for example, can have gauge factors approaching 100, however the piezoresistive materials used in these sensors have the disadvantages of temperature sensitivity and high fragility.

Certain viscous materials are known to have very high gauge factors. For example, the electrical resistance of graphene-doped, cross-linked polysilicone is known to be highly sensitive to deformation, with a gauge factor greater than 500. However, such low viscosity materials have several disadvantages due to their semi-liquid nature. For example, they present practical
5 problems of confinement or containment, and the resistance of such materials can change non-monotonically and inconsistently with deformation. It is therefore difficult to use such materials to provide consistent measurements defined by their deformation due to drift caused by the material's low viscosity, for example.

10 According to an example, there is provided an electromechanical sensor comprising a strain sensing composite material supported within a flexible matrix. In an example, the flexible matrix can be in the form of a three-dimensional (3D) lattice. The strain sensing composite material can comprise graphene and a viscoelastic polymer. Generally, a sensor comprising such a composite material would suffer from signal drift as a result of settling of the graphene component within the
15 polymer matrix due to the viscosity of the composite. However, encapsulating the composite within a flexible matrix constrains the flow of the composite material due to the closer proximity of the lattice to the composite thereby reducing or eliminating signal drift. Furthermore, the structure of the flexible matrix compounds the effect of any applied force to the sensor, thereby increasing the ability of the sensor to detect small variations.

20 The flexible matrix also allows a sensor to be more easily shaped and so incorporated into a multiplicity of devices such as wearable devices for example in which the sensor can be used to measure a person's pulse. In an example, a sensor can be incorporated into the casing of user equipment, such as a mobile phone casing or housing. This can enable the casing or housing to
25 detect the force with which it is gripped for example, thereby enabling the triggering an alarm if the device is about to be dropped for example. Other use cases for stemming from the provision of such a sensor provided in the casing and/or housing of user equipment are possible. A further advantage of using a sensor as described herein for a casing of this sort is it can be made relatively inflexible due to the high sensitivity of the composite material. That is, the high sensitivity to
30 deformation of the composite material enables a discernible and useful measure of strain to be determined over a relatively smaller range of sensor deformations compared to existing sensors. In addition, the flexible matrix can also comprise a thermal conductor, to help with heat management for a device.

35 According to an example, the strain sensing composite material comprises a mixture of graphene dispersed within a viscoelastic polymer. In an example, the graphene is in the form of graphene nanosheets. The mixture can be prepared by mixing graphene into the viscoelastic polymer in the

presence of heat. For example, 5-25% w/w graphene can be mixed into the viscoelastic polymer. The graphene nanosheets can be prepared by liquid-phase-exfoliation of graphite in, for example, N-methyl-pyrrolidone to provide nanosheets with lengths in the region of 200-800nm. The nanosheets can be transferred to chloroform and mixed with the viscoelastic polymer at, for example, a temperature in the range 40-60 deg. C. In an example, the viscoelastic polymer can be silicone oil crosslinked with boric acid.

Addition of the graphene renders the polymer conductive. The nanosheets are mobile within the polymer, which maintains its viscoelastic characteristics despite an increase in stiffness as a result of the addition of graphene. According to an example, nanosheet mobility is mitigated by defining a flexible matrix within which the strain sensing composite is provided. In an example, the flexible matrix comprises one of: elastomeric polyurethane (EPU), acrylonitrile butadiene styrene (ABS), polycarbonate (PC) and polyetherimide (PEI). The flexible matrix can be additively manufactured. For example, the flexible matrix can be 3D printed using, e.g. fused deposition modelling in which a filament of the flexible matrix material is heated to its melting point and then extruded, layer by layer, to create the matrix. The strain sensing material can be added to the matrix during the additive manufacturing process, or afterwards. For example, a print apparatus can comprise multiple print heads, at least one of which can be used to deposit the strain sensing material as desired within the flexible matrix as it is being manufactured using another print head of the apparatus.

According to an example, the flexible matrix can comprise a three-dimensional lattice structure defining a network of nodes, beams and cells. Accordingly, the strain sensing composite material can be supported within cells of the lattice structure and/or within beams and/or nodes of the lattice structure. That is, during additive manufacture of the flexible matrix, beams and/or nodes thereof can be formed hollow, with strain sensing material added into the cavity defined by the hollow beam/node as the matrix is built up layer by layer, or afterwards by, e.g., forcing the strain sensing material into the hollow regions of the matrix. By encapsulating the composite material in the flexible matrix flow is constrained due to the closer proximity of the composite material to the matrix structure thereby reducing or removing the effects of settling of nanosheets. That is, the encapsulation of the sensing material within the matrix mitigates the viscosity of the material, which would otherwise cause a signal representing the resistivity of the material to drift due to the mobility of the nanosheets.

In an example, an outer surface of the lattice structure can be so profiled as to increase surface area thereof, whereby to amplify support for the strain sensing material within the flexible matrix. Similarly, an inner surface of a node and/or beam of the lattice structure can be so profiled as to

increase surface area thereof, whereby to amplify support for the strain sensing material within the said node and/or beam. For example, an inner and/or outer surface can be roughened or include a profile or pattern.

- 5 In an example, an electromechanical sensor comprises a pair of conductive electrodes. The electrodes are so positioned on, for example, opposing sides of the flexible matrix as to detect a change in resistance of the strain sensing composite material.

10 Figures 1a-d are schematic representations of lattice structures for a flexible matrix according to an example. In particular, figures 1a to d depict side (2D) views of various different structural configurations for a lattice. The variations shown are not intended to be limiting, but merely present several exemplary lattice structures that can be used according to an example. It will be apparent that other lattice structures can be used. For example, the structures in figures 1a to d have regular unit cells. However, lattice structures with irregular unit cells can be used. In the
15 example of figures 1a-d, conductive electrodes 100a, 100b are depicted in situ on each structure. Application of a constant voltage across the electrodes 100a, 100b results in a given current which is dependent on the resistance between the electrodes. As the flexible matrix experiences a strain, the resistance of the strain sensing composite material changes thereby resulting in measurable changes to current flow that can be mapped to the strain applied. For example,
20 training data can be generated in which, for a given strain sensor, predetermined degrees of strain are applied and the resultant currents measured, thereby providing a repository of values that can be used in future to determine an applied strain for a given current.

With reference to figure 2, which is a schematic representation of the lattice structure of figure
25 1c, the flexible matrix comprises a network of nodes 200, beams 201 and cells 203. That is, nodes 200 are the intersections of two or more beams 201. A cell 203 in the example of figures 1 and 2 defines a void in the lattice structure. In an example, strain sensing composite material can be provided within cells 203 and/or within beams 201 and/or nodes 200.

30 Figure 3 is a schematic representation of the lattice structure of figures 1c and 2. In particular, figure 3 depicts a change in the shape of the structure under a strain as a result of a force F applied to the structure as it rests on two supports 301, 303. As can be seen, the shape and relative position of the nodes, beams and cells changes under strain. Accordingly, there will be a corresponding change in the resistive characteristics of an encapsulated strain sensing material
35 due to the effects that these changes in position and shape have on the graphene material. That is, as the strain sensing material changes shape as a result of the change in the shape of the encapsulating structure, the relative position of graphene nanosheets within the material will also

change (e.g. by spreading apart or being forced more closely together), thereby altering the flow of current through the material resulting in a measure for strain.

In an example, an electromechanically sensor can be fabricated using additive manufacturing. For example, a print apparatus can comprise 3 material deposition structures – one for depositing a strain sensing material as described herein, one for depositing material to form the flexible matrix, and one for depositing an electrically conductive material that can be used to form one or more conductive electrodes.

Thus, according to an example, strain sensing material can be deposited with the encapsulating material and electrodes. This enables highly sensitive strain sensors to be fabricated in virtually any shape. Furthermore, the encapsulating matrix provides a robust skeleton through the strain sensing material which can increase the strain that the material undergoes compared to the case in which the material is just encapsulated around the outside. The degree to which the strain sensing material can be strained can be tuned to match an application. For example, if a sensor will be flexed in a specific way during its application then a skeleton can be fabricated through the strain sensing material that promotes the strain in the material for that specific movement.

Figure 4 is a schematic representation of user equipment according to an example. In particular, figure 4 depicts UE 400 from one side (in cross section). The user equipment (UE) 400 can be, for example, a smart phone or other handheld portable electronic device. In the example of figure 4, the UE 400 a processor 401, and an electromechanical sensor 403. The processor 401 can be configured to receive an input signal from the electromechanical sensor 403, and generate a measure representing an orientation and/or movement of the UE 400. In the example of figure 4, the strain sensor 403 is configured as an array and positioned inside the back surface 406 of UE 400.

That is, an array of electrodes 405 is positioned to enable a strain location to be determined, such as where UE 400 is being picked up or held for example. The array 405 can measure strain/force and location so as to make the back of the UE 400 a secondary interface (e.g. secondary to a front display 407 of UE 400). In this connection, a reference electrode 408 can be provided on the back face 406 of UE 400.

In the example of a smart phone, this could maximise available screen size for a user when they are, for example, typing, playing games, or surfing the internet and so on. Furthermore, this could be used as a security feature for accessing the UE 400 by being able to capture movement of

fingers as well as force. The back surface 409 can be simply made from a thin amount of any material, e.g. plastic. The 3D printed support architecture maximises the strain that is recorded.

The array of electrodes 405, each of which can be individually addressable or addressable in sets and so on, thus enables a measure of strain applied at multiple locations on the surface of UE 400.

Figure 5 is a schematic representation of user equipment according to an example. In particular, figure 5 depicts UE 500 from one side (in cross section). The UE 500 of figure 5 is the same as that described above with reference to figure 4 with the exception that the array of electrodes 405 is positioned on the 'electronics side' of the UE 500 – that is, as part of the internal structure of the UE 500 before an outer casing. This could be advantageous for integration with the UE 500 without compromising performance. This also means the outer case 501, if electrically conductive, could double as the reference electrode.

Additional use cases for an electromechanically sensor may be, for example:

- Use a strain array on the back/side of a smart phone (or similar) for grip analysis. For example, strain force and location can be used to determine if the user is holding with all five digits and using a finger of the other hand for navigation - if this is happening while say walking/driving this is risky behaviour. Similarly, if the phone is lightly held by four fingers then the thumb of that hand is probably being used for navigation - optimise the user interface for thumb use. How people are holding future devices such as foldable phones will be important for operation/interaction.
- When the phone is on a flat surface you can determine if part of the phone is hanging over the edge - alert the user to the risk.
- Use grip analysis (combining surface strain array + phone's IMU) to determine that a phone is about to slip out of the hand. Use haptics to tell the user that a drop is eminent.
- Put the backside of the phone up and place valuables such as wallet on top. Any disturbance of load can activate an alarm.
- The strain profile of the phone's surface could be used to determine where it is - pocket, bag, etc. - adjust ring volume to take environment into account
- An alternative use is to encapsulate the battery in a thin strain mesh and detect very minor changes in battery size and shape for health monitoring purposes.

Figure 6 is a schematic representation of a wearable device according to an example. The example of figure 6 depicts a smart watch, although wearable devices can be considered perfectly suited to the incorporation of an electromechanical sensor as described herein. The wearable

600 comprises a display 601, an electromechanical sensor 603, an array of electrodes 605 (although it will be appreciated that a single electrode may be used if desired), a rear face or cover (e.g. plastic) 606, and straps 607.

- 5 The strain sensing material is sensitive enough to measure the pulse shape of a user's heart once it is encapsulated in a flexible matrix as described herein. In the example of figure 6, the wearable 600 can be additively manufactured (e.g. 3D printed). That is, in an example, the electromechanical sensor 603, array of electrodes 605, rear face or cover 606, and straps 607 can be additively manufactured. This enables the sensor to be positioned very close to a desired
10 sensor area on a user without the need for separate parts that will lead to reduced sensitivity of the device. The structure can also be shaped such that it penetrates the strain sensing material in order to maximise the strain that the material experiences in this deployment scenario. In other example, an electromechanical sensor can be used to measure power output in cycling pedals or in running shoes or even as a non-wearable device where extreme sensitivity is required for
15 example.

The present inventions can be embodied in other specific apparatus and/or methods. The described embodiments are to be considered in all respects as illustrative and not restrictive. In particular, the scope of the invention is indicated by the appended claims rather than by the
20 description and figures herein. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

CLAIMS

1. An electromechanical sensor, comprising:
a flexible matrix; and
5 a strain sensing composite material supported within the flexible matrix.
2. The electromechanical sensor as claimed in claim 1, wherein:
the strain sensing composite material comprises graphene dispersed within a viscoelastic
polymer.
10
3. The electromechanical sensor as claimed in any preceding claim, wherein:
the flexible matrix comprises one of: elastomeric polyurethane (EPU), acrylonitrile
butadiene styrene (ABS), polycarbonate (PC) and polyetherimide (PEI).
- 15 4. The electromechanical sensor as claimed in any preceding claim, wherein:
the flexible matrix comprises a three-dimensional lattice structure defining a network of
nodes, beams and cells.
5. The electromechanical sensor as claimed in claim 4, wherein:
20 the strain sensing composite material is supported within cells of the lattice structure.
6. The electromechanical sensor as claimed in claim 4 or 5, wherein:
the strain sensing composite material is supported within beams and/or nodes of the
lattice structure.
25
7. The electromechanical sensor as claimed in any of claims 4 to 6, wherein:
an outer surface of the lattice structure is so profiled as to increase the surface area
thereof, whereby to amplify support for the strain sensing material within the flexible matrix.
- 30 8. The electromechanical sensor as claimed in any of claims 4 to 7, wherein:
an inner surface of a node and/or beam of the lattice structure is so profiled as to
increase surface area thereof, whereby to amplify support for the strain sensing material within
the said node and/or beam.
- 35 9. The electromechanical sensor as claimed in any preceding claim, further comprising a pair
of conductive electrodes so positioned on opposing sides of the flexible matrix.

10. A method for fabricating an electromechanical sensor, the method comprising:
additively manufacturing a flexible matrix; and
depositing a strain sensing composite material within the flexible matrix.

5 11. The method as claimed in claim 10, wherein the strain sensing material is additively
deposited within the flexible matrix as the flexible matrix is manufactured.

12. The method as claimed in claim 10 or 11, further comprising:
depositing a pair of conductive electrodes on opposing sides of the flexible matrix.

10

13. The method as claimed in any of claims 10 to 12, further comprising:
profiling an inner and/or outer surface of the flexible matrix.

14. The method as claimed in any of claims 10 to 13, wherein the flexible matrix comprises a
15 three-dimensional lattice structure defining a network of nodes, beams and cells, and wherein
depositing the strain sensing composite material comprises depositing the strain sensing
composite material within cells of the lattice structure.

15. The method as claimed in any of claims 10 to 14, wherein the flexible matrix comprises a
20 three-dimensional lattice structure defining a network of nodes, beams and cells, and wherein
depositing the strain sensing composite material comprises depositing the strain sensing
composite material within beams and/or nodes of the lattice structure.

16. User equipment, comprising:
25 a processor; and
an electromechanical sensor as claimed in any of claims 1 to 9,
wherein the processor is configured to:
receive an input signal from the electromechanical sensor, and
generate a measure representing an orientation and/or movement of the user equipment.

30

17. User equipment as claimed in claim 16, wherein the processor is configured to derive a
measure of resistance from the electromechanical sensor, and map the derived measure of
resistance to a predetermined orientation and/or movement profile.

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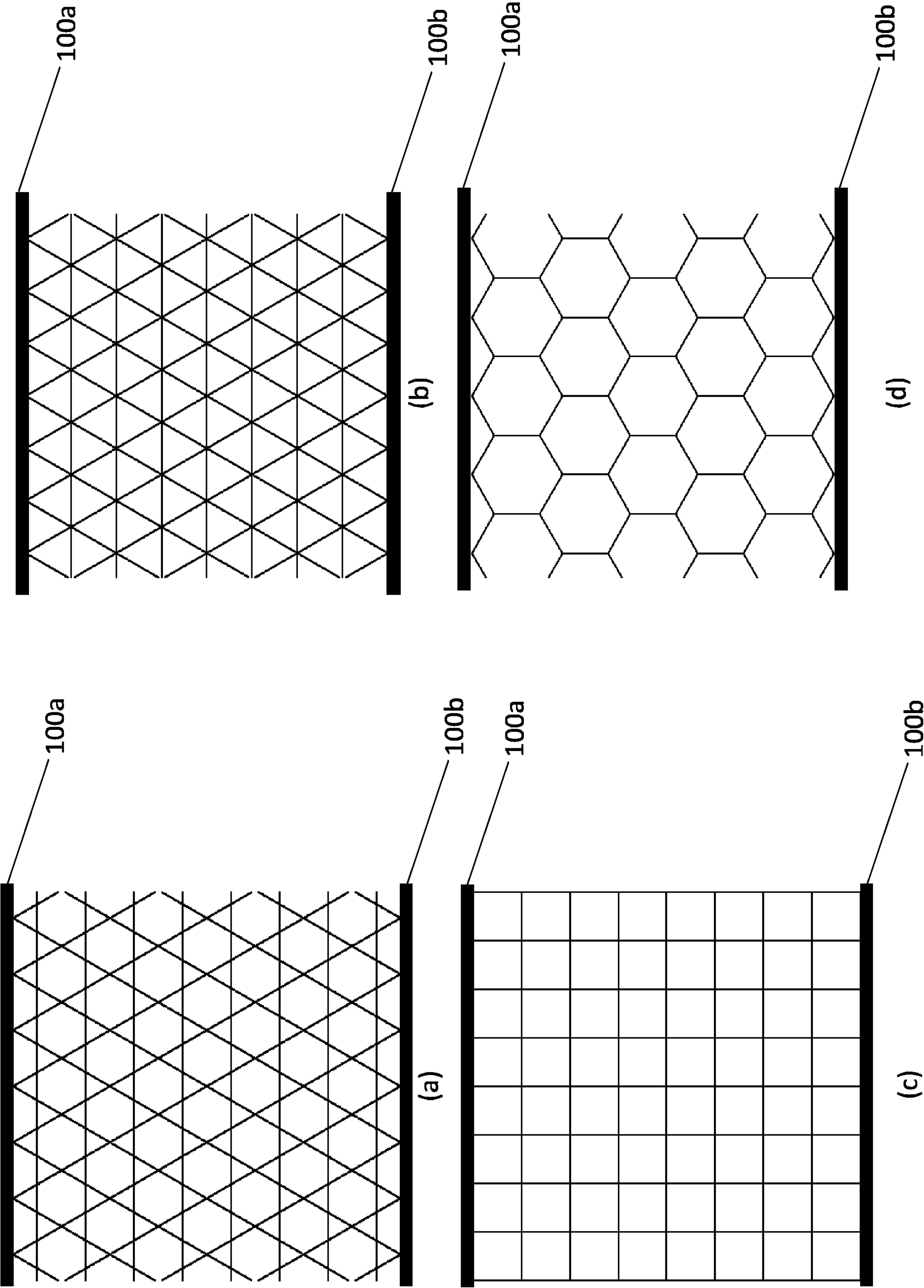


Figure 1

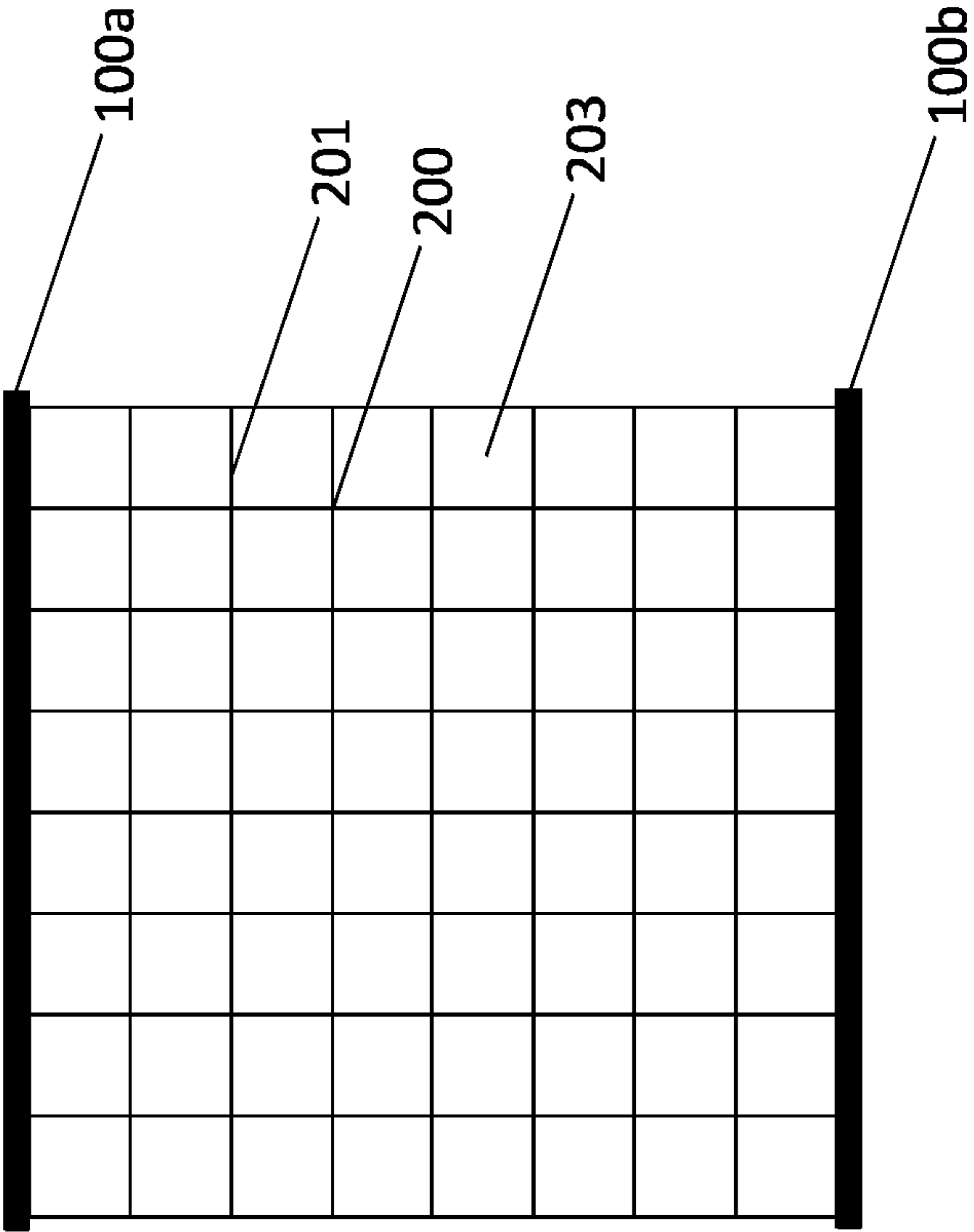


Figure 2

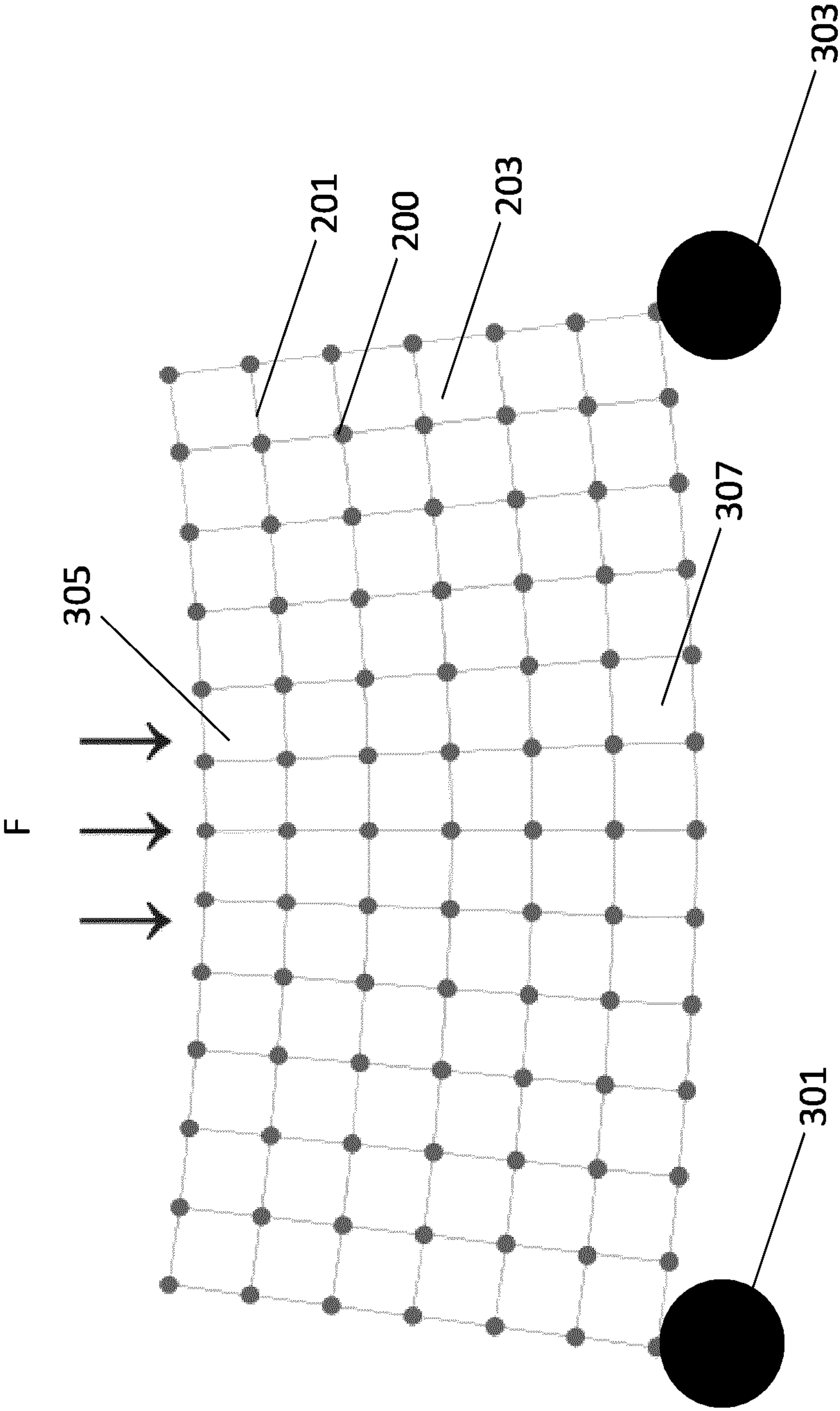


Figure 3

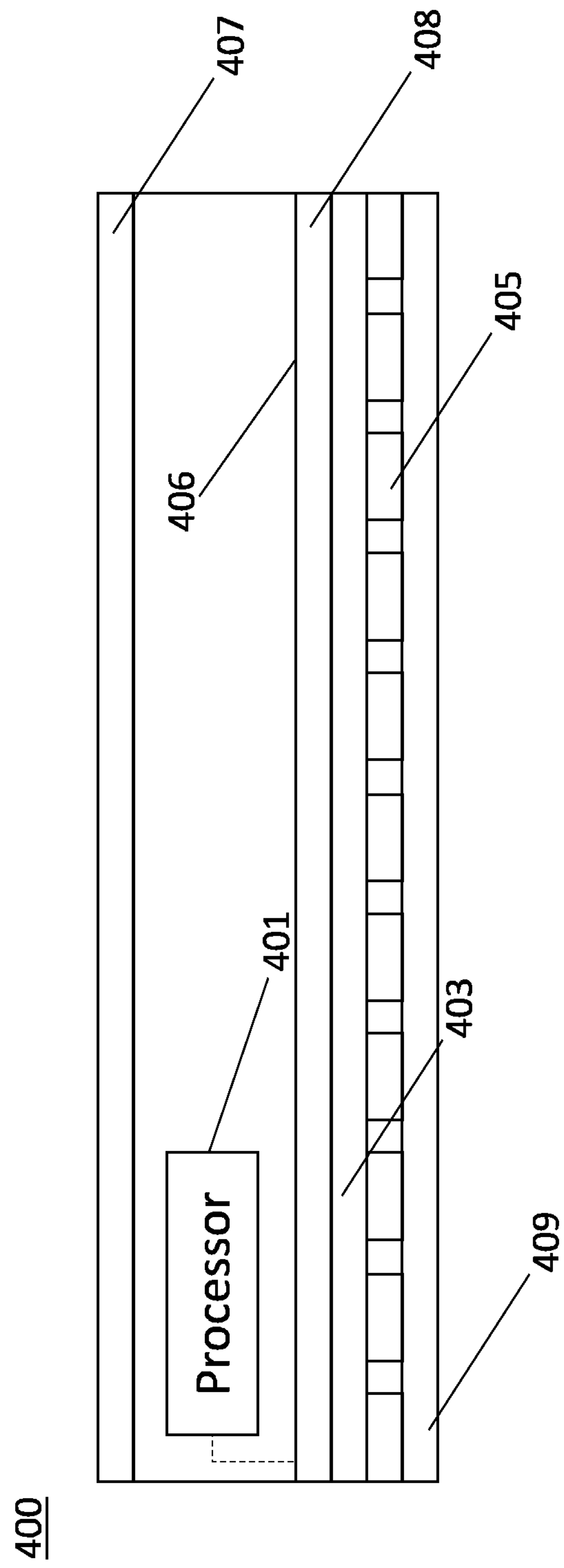


Figure 4

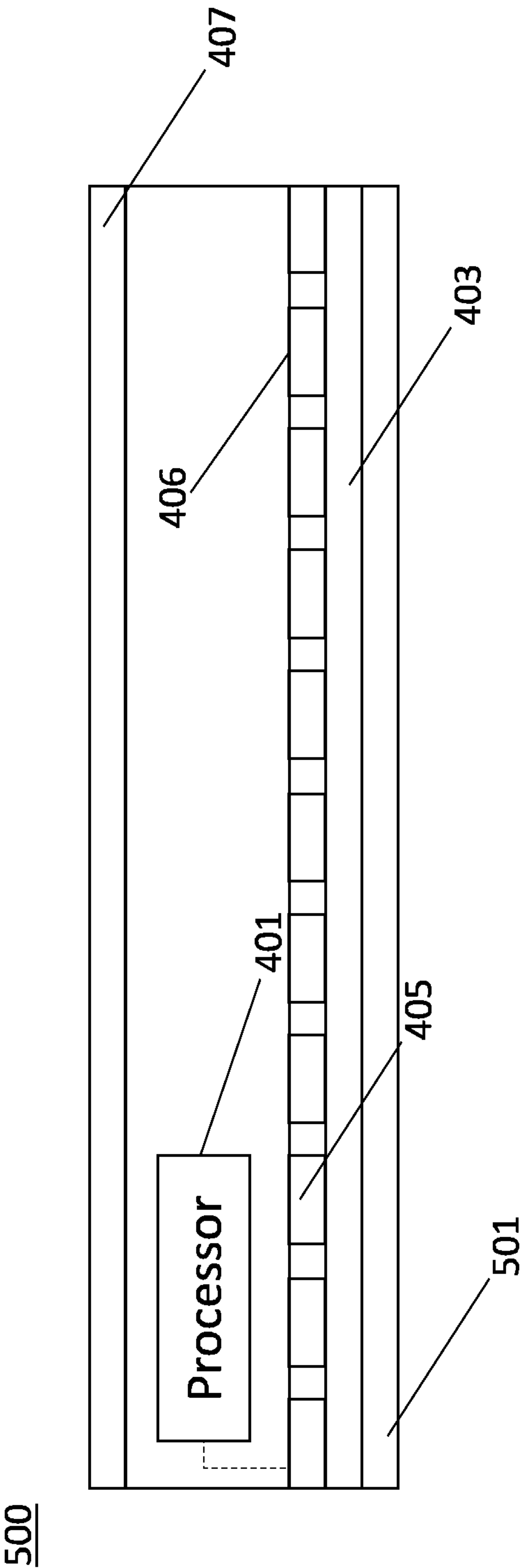


Figure 5

600

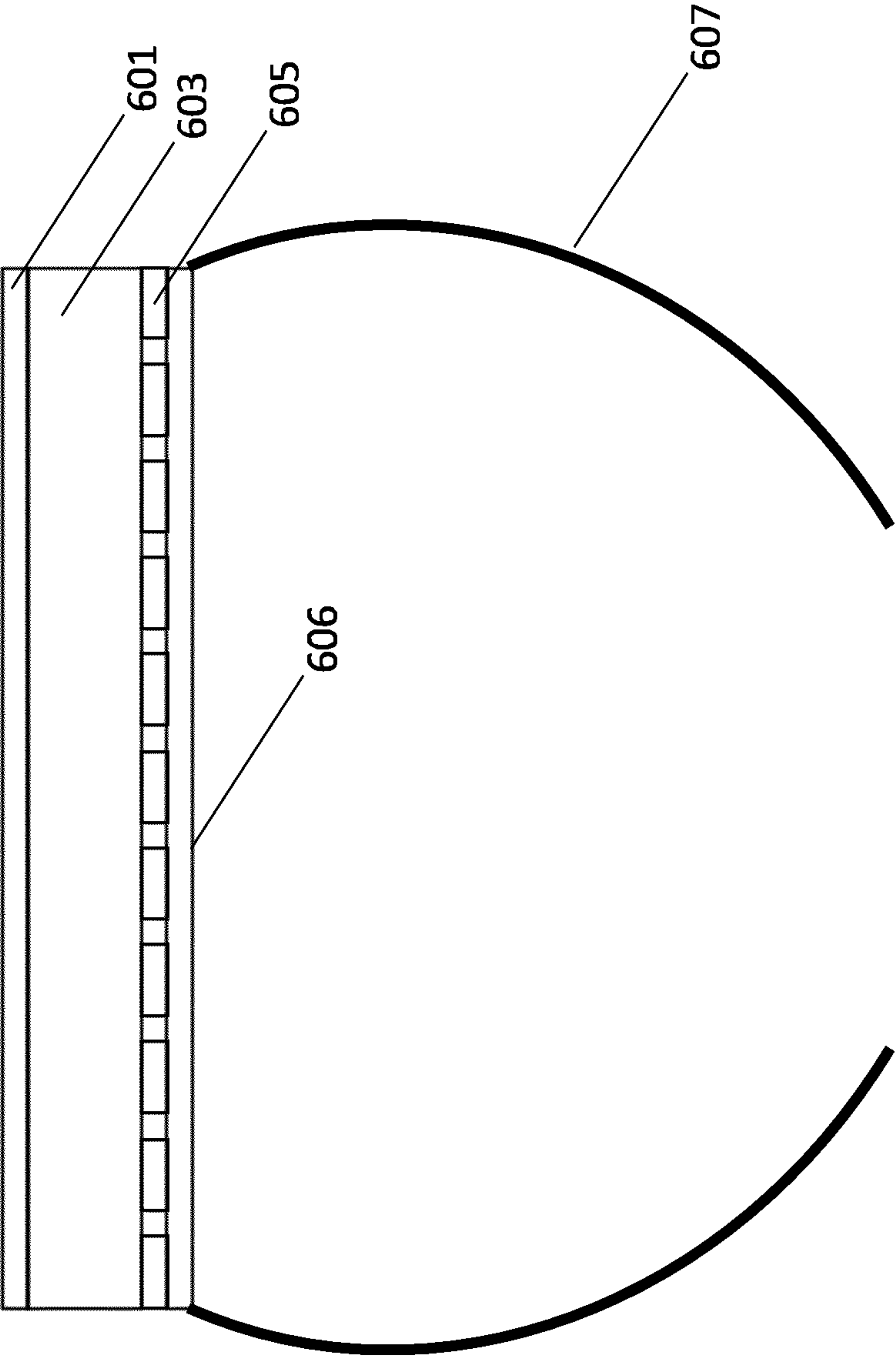


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/079689

A. CLASSIFICATION OF SUBJECT MATTER INV. G06F3/0346 G01B7/16 G01L1/18 G06F3/041 A61B5/024 G01L1/20 ADD. According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G06F G01B G01L A61B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/192501 A1 (UNIV KING ABDULLAH SCI & TECH [SA]) 20 June 2019 (2019-06-20)	1,3, 9-12,16, 17
Y	paragraphs [0007], [0040], [0047], [0066] - [0069], [0135], [0214] - [0218], [0245], [0249]; figures 27, 34 -----	2
Y	WO 2019/116135 A1 (UNIV KING ABDULLAH SCI & TECH [SA]) 20 June 2019 (2019-06-20)	2
A	paragraphs [0059] - [0065]; figures 9A-10D, 12, 13 -----	9,12,16, 17
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
24 January 2021		23/03/2021
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer González Carballo, N

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2020/079689

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-3, 9-12, 16, 17

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 9-12, 16, 17

the strain sensing composite material comprises graphene dispersed within a viscoelastic polymer;

2. claims: 4-8, 13-15

the flexible matrix comprises a three-dimensional lattice structure defining a network of nodes, beams and cells, and the strain sensing composite material is supported within cells, beams or nodes of the lattice structure;

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/079689

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016192501 A1	20-06-2019	US 2016192501 A1 WO 2014200428 A1	30-06-2016 18-12-2014

WO 2019116135 A1	20-06-2019	EP 3724596 A1 WO 2019116135 A1	21-10-2020 20-06-2019
